Manufacturing Equipment Changeover Impacts on Component Quality

by

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ABSTRACT

The new computer numerical control (CNC) machine was reviewed to determine change-over impacts on fabricated wood components. Due to the numerous manufactured component profiles this research will focus on four impacting Window Company XYZ.

The quality was based on the ability to produce components to engineering specifications and customer declarations. Samples were collect during the manufacturing process and measured to determine adherence to length quality expectations. Graphical illustrations give profile related detail surrounding the lineal adherence to implied specifications.

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Chapter I: Research Problem and Objectives

Introduction

The computer numerical control (CNC) manufacturing process has the ability to generate items from a solid form. The material used to create the item could range from metals, plastics and wood. The new CNC machine examined in this study created components from wood.

The CNC in question produced various profiles that required adherent to engineering specifications to generate quality products. The operator configured the equipment per profile to meet these set standards. In the event the equipment fabricated non-conforming components, an investigation was essential to determine cause. This was implemented through sample collection and testing. Findings are represented in tables and visually presented in graphs.

The issues encountered and their diagnoses are found in the following portions of this chapter.

Problem Statement

Which variable (material characteristics, software issues, or operator error) generated non-conforming components after the initial setup of the new CNC machine?

Research Objectives

The collection of manufactured samples will help isolate components to identify if they adhere to preset specifications.

The objectives of this study are to:

1. Determine the quantity of parts manufactured within a specified production time either failing or meeting specifications. The quantity

failing were compared to a preset quality variable which determined if an investigation was required.

2. Identify the cause of the non-conforming components.

Significance of the Study

Engineers and customers set standards for product requirements. The specifications allow the production facility to tailor equipment and processes to fulfill the standard. In the event the generated item did not meet the specifications, an investigation was required to determine causation. This action helped reduce scrap, and costs associated with the production of non-conforming product. Adherence to the preset quality standards increased customer satisfaction. It demonstrated the manufactures ability to produce components/products at a high level, minimizing non-conforming parts entering the market and impact consumers.

Limitations

The study concentrated on the CNC machine's output. The operation of the CNC took place on one shift by one trained operator. This narrowed down the possible causation of non-conforming parts.

The limitations of this study were:

1. The results of this study were limited to Window Company XYZ.
2. The findings were related only to the new CNC machine.
3. The fabricated components were only wood profiles.
4. The tests conducted were in the preliminary phase of equipment role-out.

Assumptions

The assumptions of this study were:

1. The operator has passed pre-operation training.
2. The operator has experience with the use of Heidendhain incremental linear encoder to validate measurements.
3. The components fabricated were from pine wood stock.
4. The fabricated component conformity must fall within ±0.030 of the expected length.
5. All of the raw materials were of the same quality wood grade.
6. Window Company XYZ will relocate the CNC machine within the next year.
7. Recalibration of equipment would take place when relocated.

Definitions

Change-over – Adjusting equipment and/or material to produce a distinct item compared to the prior production run.

Conforming – Manufactured component status upon meeting engineering and/or customer specifications.

Non-conforming – Manufactured component status when it does not meet engineer and/or customer specifications. The specifications were tailored to meet industry standards plus customer expectations.

Computer Numerical Control (CNC) – A computer controlled manufacturing process which uses specific programs to fabricate designs from a solid material.

National Fenestration Rating Council (NFRC) – A non-profit organization that sets industry performance standards on window and doors.

Chapter II: Review of Literature

Introduction

The literature review includes a discussion of the CNC manufacturing process. There is special focus on equipment machining function and overview of quality expectation from fabricated components. The CNC functions and quality specifications impacted the wood parts produced for Window Company XYZ.

CNC Manufacturing Process

The CNC process in this study entailed removing material from a solid piece of wood to create the end item. The drill bit composition and edge style were dependent on the profile outcome for the finished product. Each step of the process required a different bit. The three steps were routing, grooving, and drilling as illustrated in the pictures.

Figure 1 - Routing Step - Profile Bit

Routing removed the larger portions of the material. This step created the most waste due to the nature of giving shape to the raw material. The edge of the Profile bit was designed to remove sufficient material to form a desired profile. Typically the result was a rough finish.

Figure 2 – Grooving Step - Grooving Bit

Grooving gave form to the product. The bit's edge shape varied depending on the required design for the finished product. Waste was generated but to a less degree then routing. The finish of the surface was smoother.

Figure 3 - Drilling Step - Flute Bit

Drilling was the final stage of the machining work. This incorporated a smaller drill bit to complete the finishing touches. The edge of the Flute bit was designed to smooth shapes. Any visual imperfections due to wood characteristics became evident in this phase.

The quantity of bits stored in the CNC machine varied according to the number of process steps. Each step could incorporate approximately a dozen bits. The more complicated the design for the finished product increased the bit configuration.

Quality Expectations

Consumer satisfaction is vital to the success of any business. This is evident in the competitive window and door market. To maintain the rating of top window producers in the United States, window manufactures must create quality products to meet customer demand. The standards to accomplish satisfaction are based on industry standards, plus consumer requests.

The building industry sets quality requirements based on safety and performance. The expected conformances are detailed on the National Fenestration Rating Council (NFRC) label. The information listed explains the inspection agency, energy efficiency, and air leakage on the product (see figure 4). The manufacture aims to exceed the minimal requirements.

Chapter III: Research Methods

Introduction

Consumers' quality requirements are considered in product design. In an effort to understand their outlook Window Company XYZ conducted a survey on quality expectations. The consensus from the survey defined quality as '… inclusive of reliability, no need for maintenance, and an implied warranty'. (Farnsworth, pp 1, 2001) The new CNC machine was introduced into production to assist in generating consumer desired products.

Manufacturing processes were designed to generate product that adhered to industry and consumer quality standards. Internal audits were conducted on various samples to measure compliance of specifications. In the event the product fails the test, an investigation was conducted.

Research Design

Random experimental measures were performed to the four profiles generated on the CNC. The profiles were run at various frequencies and lineal dimensions compared to specifications. The mixed interval of testing the parts allowed measures throughout the manufacturing process. This method permitted the machine operator to validate measures according to product specifications. In the event of non-conformance, immediate action was taken to identify causation.

Population

- Measures conducted at the beginning of a new profile run (change-over), and after a specified time of operation based on production expectations.
- Wood components of four profiles were machined.
- Jamb profiles impacted were: Left Hand Side, Right Hand Side, Head and

Sill.

- Sample of four pieces tested at change-over and each specified interval per profile.

The fabrication of wooden components required the sample collection upon each production occurrence of a profile. The quantity sample of four pieces was determined due to the number of wood components in a manufactured window unit. The random tests following the initial set-up were performed to confirm the CNC continued to generate conforming parts.

Measurements

It was important to incorporate an accurate measuring tool to verifying component dimensions. The use of a vertical scale allowed the operator to inspect the samples adherence to specifications. The Heidendain incremental linear encoder had a tolerance ratio of ± 10 μm, enabling the device to detect diminutive variances in a product's dimensions. The device gets calibrated on a yearly basis to maintain accuracy, latest was on January 3, 2008.

Data Collection

Once the functional program was installed into the CNC for the profiled item, continual testing was required. Upon successful generation of four conforming items for a particular profile, random tests were conducted during standard operation. The operator was instructed to randomly measure four pieces every hour of continual operation. In the event of a change-over, four parts were tested initially followed by four pieces every hour. The data collected from the random tests were monitored in the span of 3 days.

Chapter IV: Manufacturing Results

Introduction

In an effort to determine the impacts of profile change-over, samples were collected through various manufacturing sessions. The sample run size consisted of four parts per profile. The four profiles: Left Handed (LH) Jamb, Head Jamb, Right Handed (RH) Jamb, and Sill Jamb were rotated to help determine the impact of CNC adjustments on the parts. Measurements were taken of the samples and compared to specifications.

Research Findings

The LH and RH side jambs production runs were conducted separately. The Head jamb fabrication transpired between the side jamb runs, with Sill jambs following the RH side jamb run. This method allowed the operator to test whether the varying dimensional change-over impacted the end length. The data was collected at specified intervals of 30 minutes and documented on a Measurement Traveler (see appendix table 2 – Measurement Traveler). The accumulation of the traveler data for this study was placed onto a table for engineering analysis (see appendix table 1 – Jamb lengths).

The Head and Sill jamb specification required the parts to measure 71.25". The component's measurement adherence to conformity required the value to fall within ±0.030" of the desired specifications. The lineal samples' measures fell within the specified tolerances (71.235"(min) and 71.265"(max)).

The measurements for the Head and Sill test runs were entered into the data calculations table illustrated in figure 5. The process capabilities were derived from the samples and value averages/ranges are expressed in the control charts. The X-bar and R-chart control charts give a visual representation of the measurements' trend.

The calculated process capabilities (Cp and Cpk) described the ability of the machining process to produce items to engineering requirements. The Cp value is the ratio of the engineering upper specification limit (USL) and lower specification limits (LSL) to the likely tolerance. A Process is considered capable if the Cp > 1. The Cpk value takes into account the ability for the process to generate product within the USL and LSL. A Cpk > 1 is considered capable. The CNC process produced values of Cp = 0.461 and Cpk = 0.2676.

Number of samples (<= 50)	6
Sample size (2 - 10)	4

Grand Average	71.2437	A2	D3	D4	d2
Average Range	0.0223	0.729	0	2.282	2.059

DATA	1	2	3	4	5	6
1	71.253	71.255	71.262	71.249	71.239	71.239
2	71.245	71.261	71.252	71.243	71.22	71.244
3	71.245	71.234	71.232	71.233	71.234	71.238
4	71.274	71.241	71.232	71.241	71.23	71.251
5						
6						
7						
8						
9						
10						
Average	71.25425	71.2478	71.2445	71.2415	71.2313	71.243
LCLx-bar	71.22743	71.2274	71.2274	71.2274	71.2274	71.2274
Center	71.24371	71.2437	71.2437	71.2437	71.2437	71.2437
UCLx-bar	71.25999	71.26	71.26	71.26	71.26	71.26
Range	0.029	0.027	0.03	0.016	0.019	0.013
LCLrange	0	0	0	0	0	0
Center	0.022333	0.02233	0.02233	0.02233	0.02233	0.02233
UCLrange	0.050965	0.05096	0.05096	0.05096	0.05096	0.05096

Process Capability Calculations			Six sigma	0.0651
Upper specification	71.265		Cp	0.461
Lower specification	71.235		Cpu	0.6543
Specific measurements	71.25		Cpl	0.2676
Variation limits	0.030"		Cpk	0.2676

Head Jamb Measurements
Sill Jamb Measurements

Figure 4 - Head and Sill Measurements Calculations

The X-bar chart presents the averages for the group samples and their trend within the specified limits. The upper control limit (UCL) and lower control limit (LCL) were calculated as 71.265 and 71.235 respectively. The plotted values depict a gradual progression toward the lower specification for each profile. This is illustrated in figure 6 - X-chart: Head and Sill Measurements.

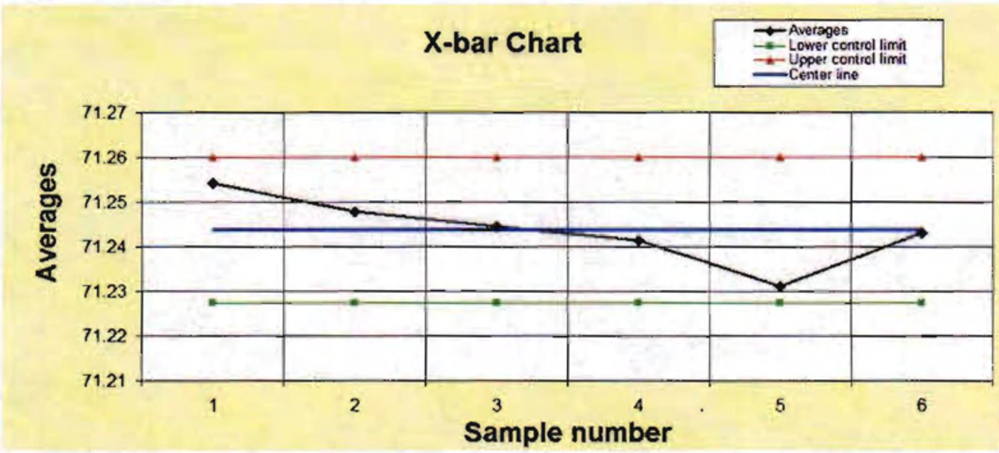

Figure 5 - X-chart: Head and Sill Measurements

R-chart plots the value range for the sample groups. The Head values (samples 1-3) and Sill values (samples 4-6) are seen in figure 7 - R-chart: Head and Sill Measurements.

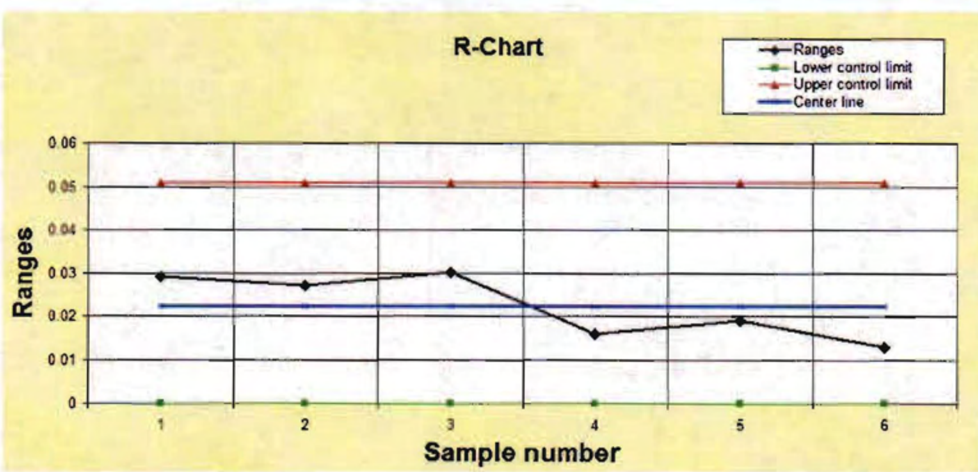

Figure 6 - R-chart: Head and Sill Measurements

The Left Hand(LH) Side jamb and Right Hand(RH) Side jamb were produced with the same variation as the Head/Sill jambs; ±0.030" of the desired specifications. The manufacturing specifications required the sides to measure 35.25", with minimum tolerance equal to 35.235 and maximum tolerance equal to 35.265.

The measurements for the side jamb test runs were entered into the calculations table illustrated in figure 8 – Side Measurements Calculations. The process capabilities were derived from the group samples and value averages/ranges are expressed in the control charts. The CNC process generated values of Cp = 0.4715 and Cpk = 0.2777.

Number of samples (<= 50)	6
Sample size (2 - 10)	4

Grand Average	35.2438	A2	D3	D4	d2
Average Range	0.0218	0.73	0	2.282	2.059

DATA	1	2	3	4	5	6
1	35.252	35.247	35.235	35.3	35.249	35.245
2	35.253	35.226	35.230	35.3	35.246	35.261
3	35.227	35.255	35.238	35.2	35.261	35.228
4	35.246	35.248	35.235	35.2	35.24	35.242
5						
6						
7						
8						
9						
10						
Average	35.2445	35.244	35.2345	35.25	35.249	35.244
LCLx-bar	35.22792	35.2279	35.2279	35.23	35.2279	35.2279
Center	35.24383	35.2438	35.2438	35.24	35.2438	35.2438
UCLx-bar	35.25975	35.2597	35.2597	35.26	35.2597	35.2597
Range	0.026	0.029	0.008	0.014	0.021	0.033
LCLrange	0	0	0	0	0	0
Center	0.021833	0.02183	0.02183	0.022	0.02183	0.02183
UCLrange	0.049824	0.04982	0.04982	0.05	0.04982	0.04982

Process Capability Calculations			Six sigma	0.0636
Upper specification	35.265		Cp	0.4715
Lower specification	35.235		Cpu	0.6654
Specific measurements	35.25		Cpl	0.2777
Variation limits	0.030"		Cpk	0.2777

LH Jamb Measurements
RH Jamb Measurements

Figure 7 – Side Measurements Calculations

The X-chart plotted the group sample averages for LH values (samples 1-3) and RH values (samples 4-6) seen in figure 9 – X-chart: Side Jamb Measurements. The upper control limit (UCL) and lower control limit (LCL) were calculated as 35.265 and 35.235 respectively. The plotted values depict a gradual progression toward the lower specification for each profile.

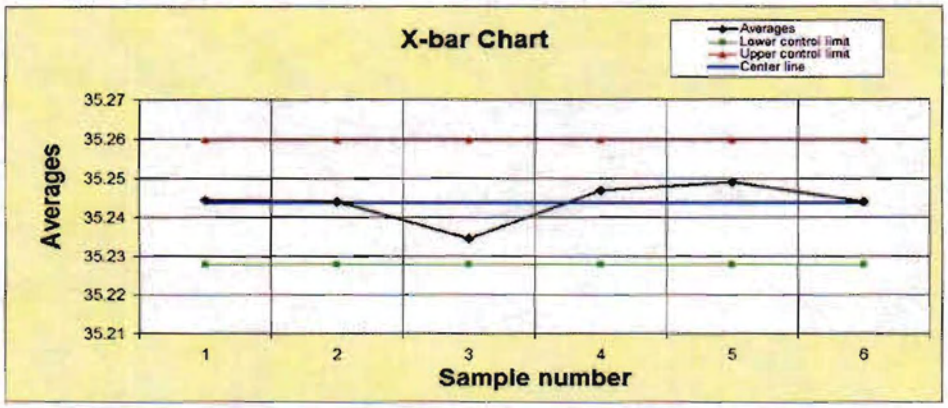

Figure 8 - X- chart: Side Jamb Measurements

The R-chart range for the side jamb sample groups (LH values (samples 1-3) and RH values (samples 4-6)) are seen in figure 10 - R-chart: Side Jamb Measurements. The LH and RH values show an increased variation between initial and final samples.

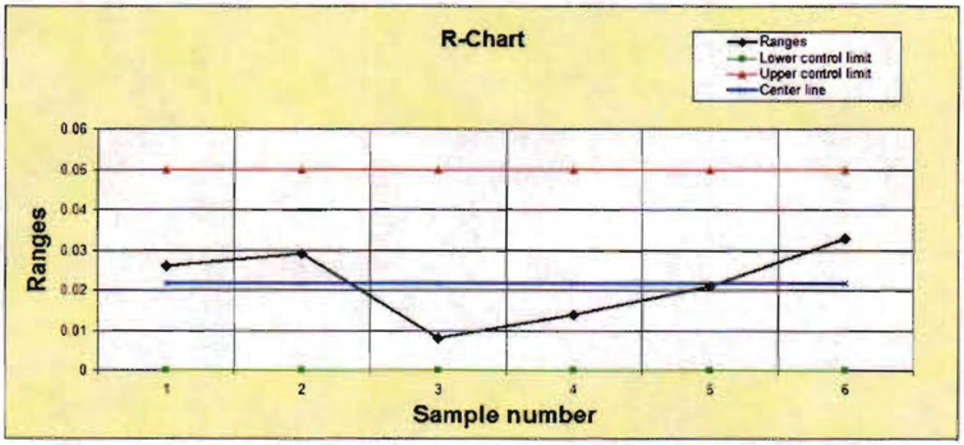

Figure 9 - R-chart: Side Jamb Measurements

Chapter V: Summary, Conclusions and Recommendations

Introduction

The computer numerical control (CNC) manufacturing process has the ability to generate items from a solid form. The new CNC machine examined in this study created components from pine wood stock.

Statement of the Problem

Identification of the variable (material characteristics, software issues, or operator error) resulting in non-conforming components after the initial setup of the new CNC machine.

Summary of Study Procedures

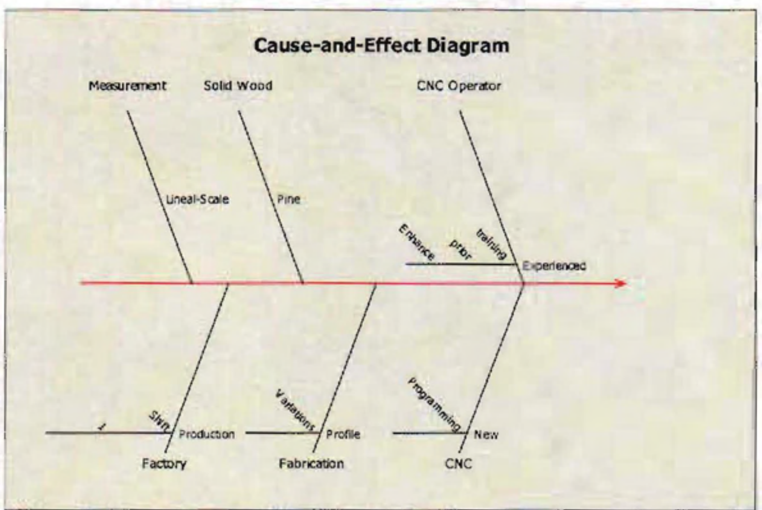

Figure 10 – Cause-Effect Diagram CNC Process

The fish bone diagram outlines the areas impacted by the CNC process to produce a quality component. The key areas directly affecting the output were the operator and CNC programming. Special focus was taken to establish each.

The operator selected to run the CNC had previous experience on a similar machine. Training was conducted for one week by the Manufacturing Engineer to enhance the operator's ability. This enabled the operator to become familiar with the programming of the CNC and its impact on the generated components.

The initial set-up by profile prior to a production run required a test sample of four components. The generated parts were measured on the Heidendain vertical scale. The measurements were compared to the established component lineal specifications. In the event all four were non-conforming, CNC settings were reviewed and a second sample collected.

Successful creation of the four conforming parts drove the operator to continue manufacturing the profile. Every hour of continuous operation, the operator would conduct a sample test of four parts. The lineal measures were placed on the traveler (see appendix table 2). The accumulated travelers were documented in the Jamb Length table (see appendix table 1) at the end of the shift. The production runs were conducted only on the day shift to give the operator access to engineering staff.

Conclusions and Implications

The CNC operation was structured to generate jamb profiles in the order of LH Side, Head, RH Side, and Sill. This variation required multiple adjustments to the equipment to produce each profile. The purpose was to determine if the change-over impacted length quality on the components.

The lineal measurements for each profile generated variations within the established parameters. The lengths fell within the specified limitations and were ±0.030" of the established specifications for each jamb type.

Although parts generated were conforming per engineering specification, the process produced varying lengths per profile. The variations in the sample means are visible in the X-bar chart with lengths nearing the LSL for each profile. The R-chart for the profiles also demonstrated shifts between measures.

The Cp value for Head/Sill Jambs equaled 0.461 and Cpk equaled 0.2676. The Side Jambs (LH and RH) produced values of Cp equal to 0.4715 and Cpk equal to 0.2777. The required value to signify stability in the process was Cp > 1 and Cpk > 1. The process capability values supported the control charts data of instability in the fabrication of the components due to programming configurations in the CNC.

Recommendations

The variation between profile types was a great method to test CNC impact on component quality length. Increasing the frequency of the change-over among the profiles could help identify the length discrepancy from the specified value sooner in the manufacturing process. This would require additional CNC configuration for the profiles and enables the operator to inspect more components in a shorter time frame.

The research findings recommend adding the time of sample collection to the measurement traveler. This would enable the engineer to help isolate the occurrence of issues based on equipment operation. It could identify where in the process the variation transpired.

Recommendations for Future Research

- Evaluate the established guidelines for operating the CNC.
- Conduct an analysis on the process steps taken by the operator and describe in statistical form by the process performance index.

- Increase the number of trained operators in an effort to identify possible human errors.
- Increase the number of wood profiles to test CNC adaptability.
- Incorporate various hardwood species to determine CNC bit impacts on profile quality.

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Appendix

Table 1 – Jamb Lengths

Unit #	Left Side Jamb Length	Met Specifications (T,F) ±0.030" of 35.25	Right Side Jamb Length	Met Specifications (T,F) ±0.030" of 35.25	Head Jamb Length	Met Specifications (T,F) ±0.030" of 71.25	Sill Length	Met Specifications (T,F) ±0.030" of 71.25
1	35.252	TRUE	35.252	TRUE	71.253	TRUE	71.249	TRUE
2	35.253	TRUE	35.252	TRUE	71.245	TRUE	71.243	TRUE
3	35.227	TRUE	35.246	TRUE	71.245	TRUE	71.233	TRUE
4	35.246	TRUE	35.238	TRUE	71.274	TRUE	71.241	TRUE
5	35.247	TRUE	35.249	TRUE	71.255	TRUE	71.239	TRUE
6	35.226	TRUE	35.246	TRUE	71.261	TRUE	71.220	FALSE
7	35.255	TRUE	35.261	TRUE	71.234	TRUE	71.234	TRUE
8	35.248	TRUE	35.240	TRUE	71.241	TRUE	71.232	TRUE
9	35.257	TRUE	35.259	TRUE	71.262	TRUE	71.239	TRUE
10	35.235	TRUE	35.245	TRUE	71.252	TRUE	71.244	TRUE
11	35.230	TRUE	35.261	TRUE	71.232	TRUE	71.238	TRUE
12	35.238	TRUE	35.228	TRUE	71.232	TRUE	71.251	TRUE
13	35.235	TRUE	35.242	TRUE	71.260	TRUE	71.228	TRUE

Table 2 – Measurement Traveler

Casement/Awning/Venting Transom Measurement Traveler

Unit # ________

Feature #	Frame Features - Fabrication	Measurement	Initials	Comments	Measurement Instrument
1	Left Side Jamb Length				Vertical Scale
2	Right Side Jamb Length				Vertical Scale
3	Head Jamb Length				Vertical Scale
4	Sill Length				Vertical Scale